Intel® Q35 Express Chipset Memory Controller Hub for Embedded Applications

Thermal Design Guide

September 2007

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Revision History

Revision Number	Description	Revision Date
001	Initial public release of this document.	September 2007

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1 Introduction

1.1 Overview

This document describes thermal design guidelines for using the embedded Intel® Q35 Memory Controller Hub (GMCH) in 1U and PICMG*1.3 form factors. The objective of designing the thermal solution is to maintain the case temperature of the GMCH below the maximum allowable case temperature as specified in the *Intel® 3 Series Express Chipset External Design Specification*. For details of the form factors, please refer to the respective form factor websites for the full specifications. Detailed mechanical and thermal specifications for this product can be found in the *Intel® 3 Series Express Chipset External Design Specification*.

The information provided in this document is for reference only; additional validation must be performed prior to implementing the thermal designs into final production. The intent of this document is to assist embedded OEMs with the development of thermal solutions for their individual designs. It is the responsibility of each OEM to validate the thermal solution design, including the heatsink, attachment method, and thermal interface material (TIM) with their specific applications.

1.2 Document Goals

This document describes the thermal characteristics and reference solution for the Intel® Q35 Express Chipset GMCH in the form factors including 1U and PICMG1.3.

1.3 Document Scope

This document includes techniques and consideration for thermal solution design in using the Intel® Q35 GMCH in an embedded application for the 1U and PICMG1.3 form factors. Reference solutions are shared later in the document. Please refer to the product datasheet for the product dimensions, thermal power dissipation, and maximum case temperature. In case of conflict, the data in the product datasheet supersedes any data in this document.

In this document the use of the term chipset refers to the combination of the (G)GMCH and the Intel® ICH9. For ICH9 thermal details please refer to the Intel® I/O controller Hub 9 (ICH9) Thermal Design Guidelines.

1.4 References

Material and concepts available in the following documents may be beneficial when reading this document.

Document	Source/Reference Number
Intel® 3 Series Chipset Datasheet	Available Electronically
Intel® Q35/Q33/G33/P33 Express Chipsets Thermal and Mechanical Design Guidelines	Available Electronically
Intel® I/O Controller Hub 9 (ICH9) Family Thermal and Mechanical Design Guidelines	http://www.intel.com/design/chipsets/designex/316974.htm
ATX and BTX System Thermal Design Guide	http://www.formfactors.org/
PICMG1.3 Specification	http://www.picmg.org/v2internal/SHB_Express.htm
Thin Electronics Bay Specification	http://ssiforum.org/specifications.aspx

1.5 Definition of Terms

Term	Description
CFM	Cubic feet per minute.
LFM	Linear feet per minute.
PCB	Printed circuit board.
T_A	The measured ambient temperature locally surrounding the processor. The ambient temperature should be measured just upstream of a passive heatsink or at the fan inlet for an active heatsink. Also referred to as T_{LA}.
T_C	The case temperature of the GMCH, measured at the geometric center of the topside of the GMCH silicon die.
T_E	The ambient air temperature external to a system chassis. This temperature is usually measured at the chassis air inlets.
T_S	Heatsink temperature measured on the underside of the heatsink base, at a location corresponding to T_C.
$T_{C\text{-}MAX}$	The maximum case temperature as specified in a component specification.
Ψ_{JA}	Junction-to-ambient thermal characterization parameter (psi). A measure of thermal solution performance using total package power. Defined as $(T_J - T_A)$ / TDP. **Note:** Heat source must be specified for Ψ measurements.
Ψ_{JS}	Junction-to-sink thermal characterization parameter. A measure of thermal interface material performance using total package power. Defined as $(T_J - T_S)$ / TDP. **Note:** Heat source must be specified for Ψ measurements.

Term	Description
Ψ_{SA}	Sink-to-ambient thermal characterization parameter. A measure of heatsink thermal performance using total package power. Defined as $(T_S - T_A)$ / TDP. **Note:** Heat source must be specified for Ψ measurements.
TIM	Thermal Interface Material: The thermally conductive compound between the heatsink and the processor case. This material fills the air gaps and voids, and enhances the transfer of the heat from the processor case to the heatsink.
P_{MAX}	The maximum power dissipated by a semiconductor component.
TDP	Thermal Design Power: A power dissipation target based on worst-case applications. Thermal solutions should be designed to dissipate the thermal design power.
Bypass	Bypass is the area between a passive heatsink and any object that can act to form a duct. For this example, it can be expressed as a dimension away from the outside dimension of the fins to the nearest surface.
Thermal Monitor	A feature on the Intel® Pentium® M processor that attempts to keep the processor's die temperature within factory specifications.
TCC	Thermal Control Circuit: Thermal Monitor uses the TCC to reduce die temperature by lowering effective processor frequency when the die temperature is very near its operating limits.
T_{DIODE}	Temperature reported from the on-die thermal diode.
U	A unit of measure used to define server rack spacing height. 1U is equal to 1.75 inches, 2U equals 3.50 inches, etc.
SHB	System Host Board.

2 Product Specifications

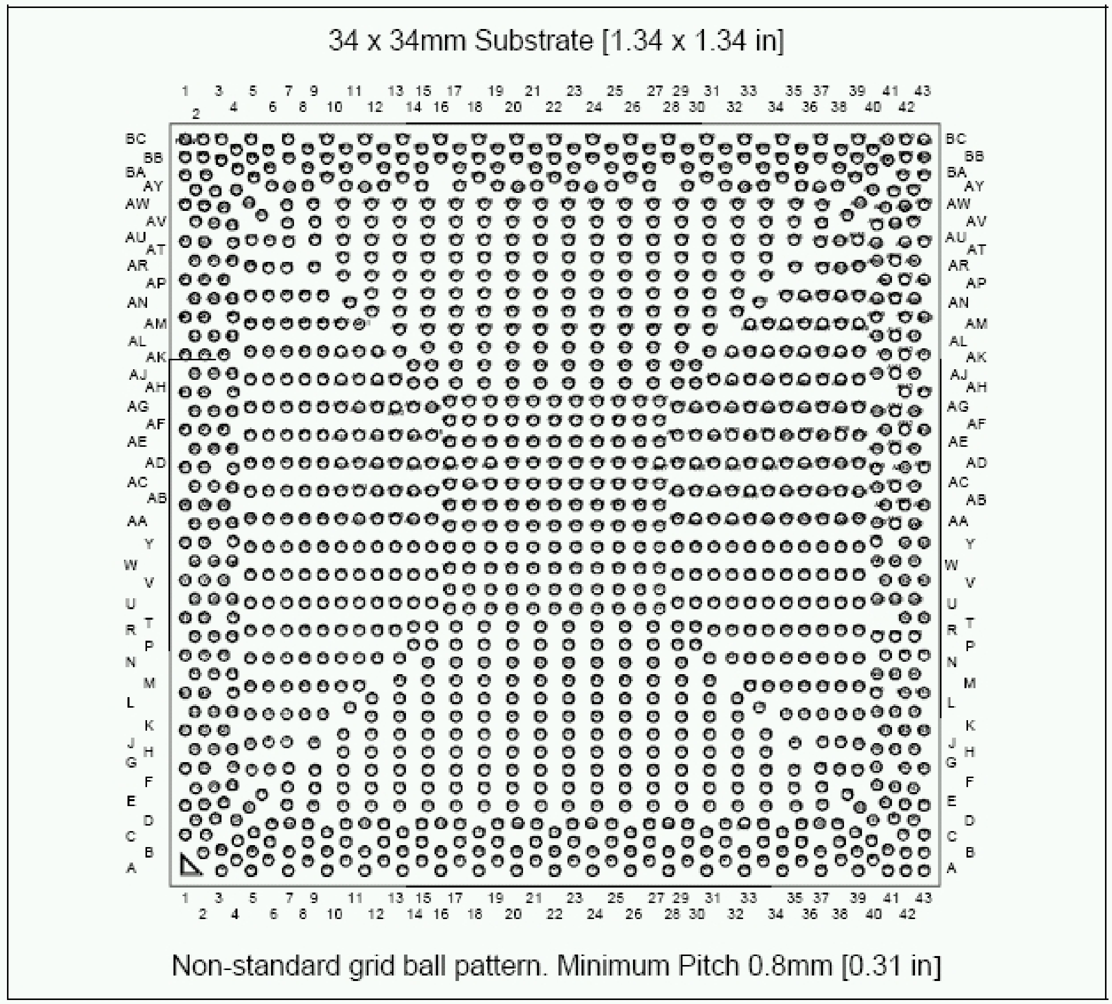
The reference solution presented in this document is targeted to provide a cooling solution of the Intel® Q35 Express Chipset GMCH in 1U and PICMG1.3 form factors. Therefore, the thermal solution will have to fit into the solution space as defined in the various form factor specifications. The reference solutions could be adapted to other form factors; however, individual assessment and verification should be done. For ATX and BTX form factors, please refer to *Intel® 3 Series Chipsets — Thermal and Mechanical Design Guide*.

Performance results provided by the reference solution should be viewed as reference only. In addition, the data implies no statistical significance. Final verification should be based on end user configuration at the system integrator or customer area.

2.1 Package Description

The GMCH package measures 34 mm x 34 mm in an FCBGA package with 1226 solder balls with a die size of 10.41 mm x 10.41 mm and a ball pitch of 0.8 mm. See Appendix B for a mechanical drawing of the package. The GMCH package uses “ball anywhere” design, so board designers should refer to the *Intel® 3 Series Chipset Datasheet* for exact ball locations relative to the package.

Figure 1. GMCH Non-Grid Array



2.2 Package Loading Specifications

The maximum mechanical loading should not exceed the specifications listed in Table 1 during heatsink assembly, shipping, or normal use. The package substrate should not be used as a mechanical reference or load-bearing surface for the thermal and mechanical solution. The post reflow package height should be utilized for heatsink clip preload calculation. Please refer to Appendix B for a mechanical drawing of the package when doing the detail analysis on preload calculation.

Table 1. Package Loading Specification

Parameter	Maximum	Notes
Static	15 lbf	1,2,3

NOTES:

1. Uniform compressive loading applied to the package.
2. Maximum allowed load from the heatsink retention clip. Minimum load must also be achieved to ensure adequate force between the heatsink and package for heat transfer.
3. These specifications are based on limited testing for design characterization. Loading limits are for the package only.

2.3 Thermal Specifications

The purpose of the thermal management is to ensure the case temperature of the GMCH is at or below the $T_{c\text{-}max}$ as defined in Table 2. This will help to achieve the product reliability target and ensure proper operation. The GMCH should also be operating above $T_{c\text{-}min}$ as stated in Table 2.

2.3.1 Definition

Thermal Design Power (TDP) is the estimated power dissipation of the GMCH based on normal operating conditions, including Vcc and $T_{c\text{-}max}$, while executing real worst-case, power-intensive applications. This value is based on expected worst-case data traffic patterns and usage of the chipset and does not represent a specific software application. TDP attempts to account for the expected increases in power due to variation in GMCH current consumption due to silicon process variation, processor speed, DRAM capacitive bus loading, and temperature. However, since these variations are subject to change, the TDP cannot ensure that all applications will not exceed the TDP value.

The system designer must design a thermal solution for the GMCH such that it maintains T_c below $T_{c\text{-}max}$ for the sustained power level equal to the TDP. The $T_{c\text{-}max}$ specification represents the limit for a sustained power level equal to TDP, and case temperature must be maintained at less than $T_{c\text{-}max}$ when operating at power levels less than TDP. The TDP can be used for thermal design if thermal protection mechanisms are enabled. The GMCH incorporates a hardware-based failsafe mechanism to keep the product temperature in specification in the event of unusually strenuous usage above the TDP power.

Table 2. Thermal Design Power

Component	System Bus Speed	Memory Frequency	Idle Power	TDP	$T_{c\text{-}min}$	$T_{c\text{-}max}$	TDP
Intel® Q35 GMCH	1333 MT/s	800 MT/s	6.5W	15W	0° C	106° C	1,2,3,4,5

NOTES:

1. Thermal specifications assume an attached heatsink is present.
2. Idle Power referred to is as a typical part of a system booted to Microsoft* Windows* without background application(s).
3. Idle data is measured for Energy Start with C23/ASPM enabled.
4. The system configuration is 2 DDR2 DIMMs per channel, FSB operating at top speed allowed by the chipset, with a processor operating at the system bus speed. Because of the FCBGA package's poor heat transfer capability through the board, it is required to have a heatsink attached to the package when using GMCH.
5. As per study, TDP data with DDR2 is higher than with DDR3.

2.3.2 $T_{control}$ Limit

Advanced Fan Speed Control monitors are used as embedded thermal sensors. The maximum operating limit when monitoring with these thermal sensors is $T_{control}$. For the Intel® Q35 GMCH, this value has been defined as 93°C. This value should be programmed into the appropriate register of Intel® Quiet System Technology (Intel® QST) as the maximum sensor temperature for the operation of the GMCH.

3 Thermal Metrology

The system designer must measure temperatures in order to accurately determine the thermal performance of the system. Intel has established guidelines for the proper techniques for measuring GMCH component case temperatures.

3.1.1 Case Temperature Measurements

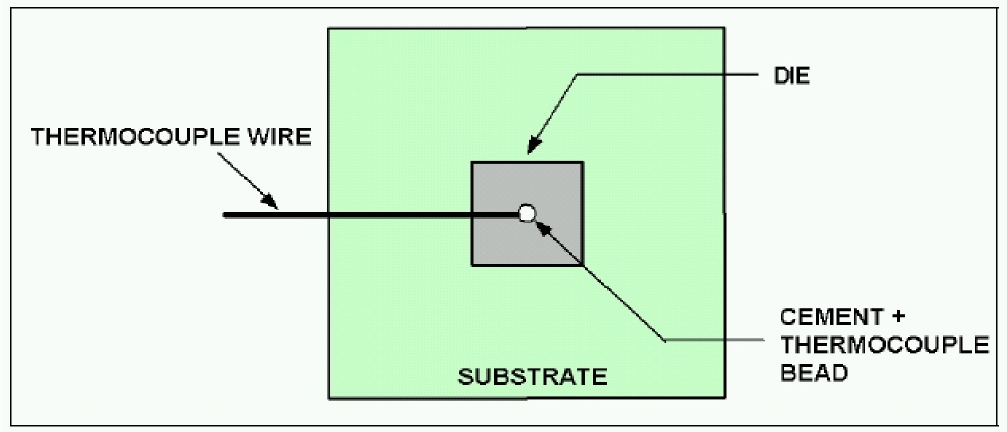
To ensure functionality and reliability of the GMCH, the T_c must be maintained at or below the maximum temperature listed in Table 2. The surface temperature measured at the geometric center of the die corresponds to T_c. Measuring T_c requires special care to ensure an accurate temperature reading.

Temperature differences between the temperature of a surface and the surrounding local ambient air can introduce error in the measurements. The measurement errors could be due to a poor thermal contact between the thermocouple bead and the surface of the package, heat loss by radiation and/or convection, conduction through thermocouple leads, or contact between the thermocouple cement and the heatsink base (if a heatsink is used). To minimize these measurement errors, a thermocouple attached with a zero-degree methodology is recommended.

3.1.2 Thermocouple Attach Methodology

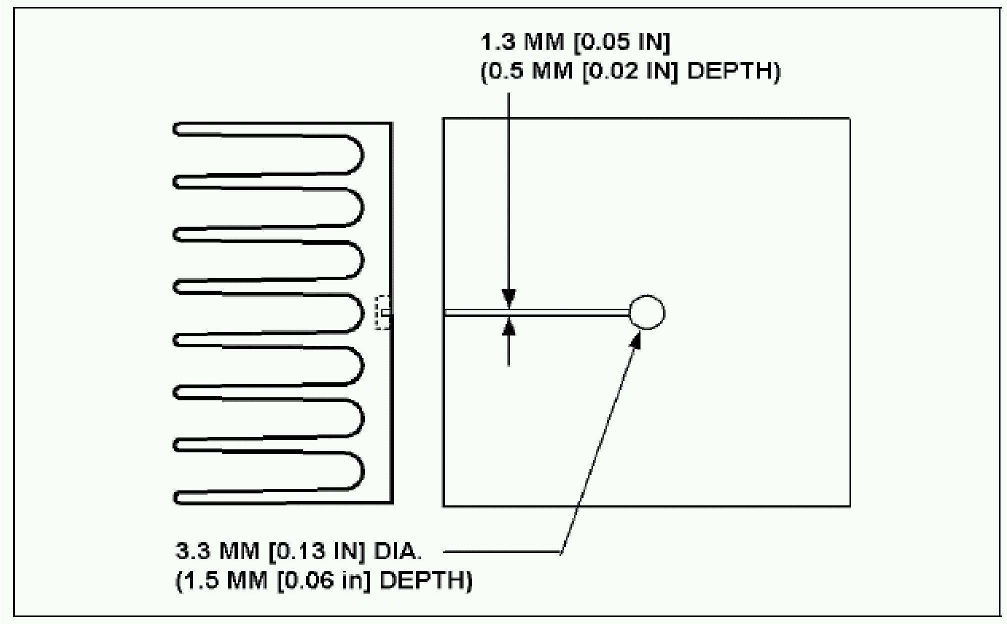
1. Mill a 3.3 mm diameter hole in the bottom center of the heatsink base. The milled hole should be approximately 1.5 mm deep.
2. Mill a 1.3 mm wide slot, 0.5 mm deep, from the centered hole to one edge of the heatsink. The slot should be parallel with the heatsink fins. See Figure 2. 0° Angle Attach Methodology (Top View).
3. Attach thermal interface material (TIM) to the bottom of the heatsink base.
4. Cut out portions of the TIM to make room for the thermocouple wire and bead. The cutout should match the slot and hole milled into the heatsink base.
5. Attach a 36-gauge or smaller type-K thermocouple bead to the center of the top surface of the die using cement with high thermal conductivity. During this step, make sure there is no contact between the thermocouple cement and the heatsink base, because any contact will affect the thermocouple reading. It is critical that the thermocouple bead makes contact with the die. See Figure 2. 0° Angle Attach Methodology (Top View).
6. Attach the heatsink assembly to the GMCH, and route the thermocouple wires out through the milled slot.

Figure 2. 0° Angle Attach Methodology (Top View)



Note: Figure not to scale

Figure 3. 0° Angle Attach Heatsink Modifications (Generic Heatsink, Side and Bottom View)

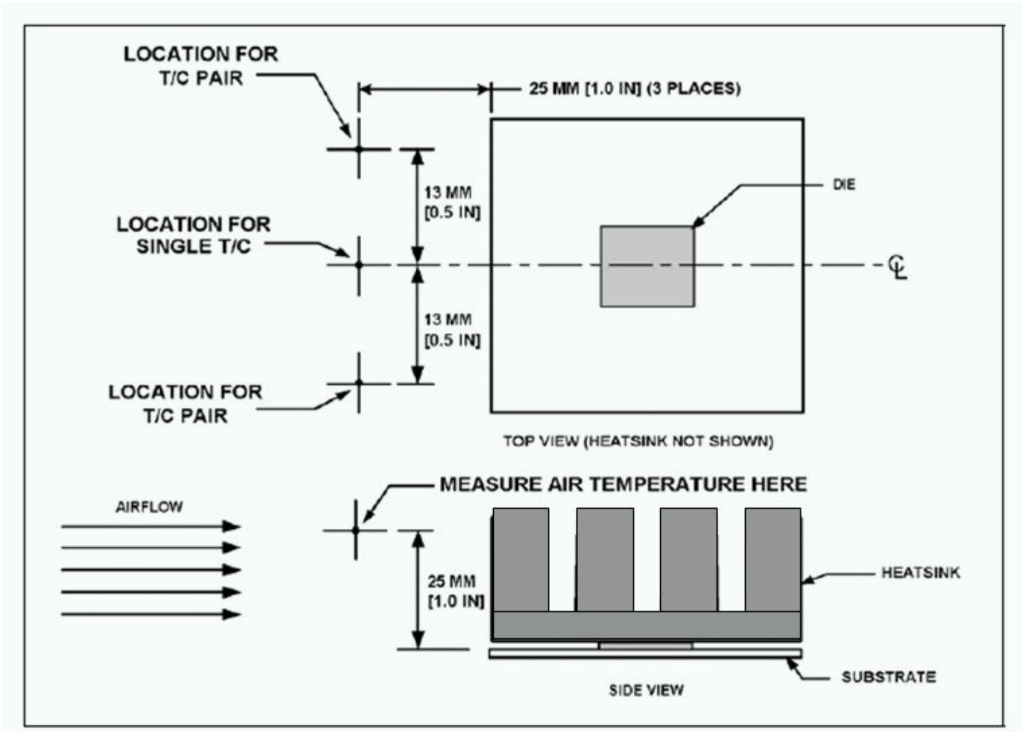


Note: Figure not to scale

3.2 Air Flow Characterization

The recommended air temperature measurement location is shown in Figure 4, with all measurements relative to the component. For a more accurate measurement of the average approach air temperature, it is recommended to take the average reading from two thermocouples spaced about 25 mm apart. Locations for single and paired thermocouples are shown in Figure 4.

Figure 4. Air Flow and Temperature Measurement Locations



Air flow velocity can be measured using sensors that combine air velocity and temperature measurements. Typical airflow sensor technology may include hot wire anemometers. Figure 4 provides guidance for airflow velocity measurement locations, which should be the same as for temperature measurement. These locations are for a typical JEDEC test setup and may not be compatible with chassis layouts due to the proximity of the processor to the GMCH. It may be necessary to adjust the locations for a specific chassis. Be aware that sensors may need to be aligned perpendicular to the airflow velocity vector or an inaccurate measurement may result. Measurements should be taken with the chassis fully sealed in its operational configuration to achieve a representative air flow profile within the chassis.

3.3 Thermal Test Vehicle

A thermal test vehicle (TTV) is available for early thermal testing prior to the availability of the actual silicon. The TTV contains heater die and can be powered up to a desired power level to simulate the heating of a GMCH package. The TTV must be surface mounted to the custom design board to provide required connectivity to power up the heater. It is recommended to do final validation using the actual production

silicon, even though the TTV is made to closely match the actual silicon in mechanical form and fit. The TTV mechanical features, including die size, ball, count, etc., may not reflect those of the final production package.

Please contact your Intel field representative regarding availability of the GMCH TTV for development needs.

3.4 Thermal Management Guidelines

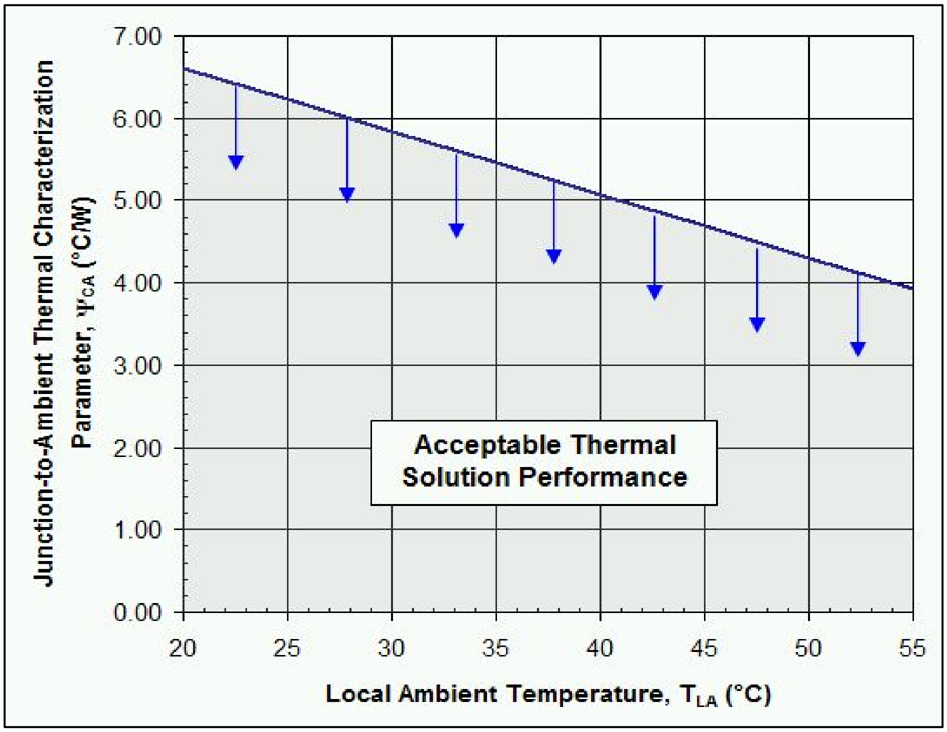
Thermal performance of thermal solution depends on many parameters, including the following product characteristics:

1. Thermal Design Power
2. Maximum case temperature (T_{c-max})
3. Operating ambient temperature
4. Air flow
5. Interface between the thermal solution and the silicon die of the package (TIM, pressure, flatness, etc.)

It is strongly recommended that the design team validate the reference thermal solution with the end use condition to ensure all environmental variables are considered and the reliability of the solution is tested.

Please refer to Figure 5 for the required thermal performance in order to cool the GMCH to at or below the T_{c-max}.

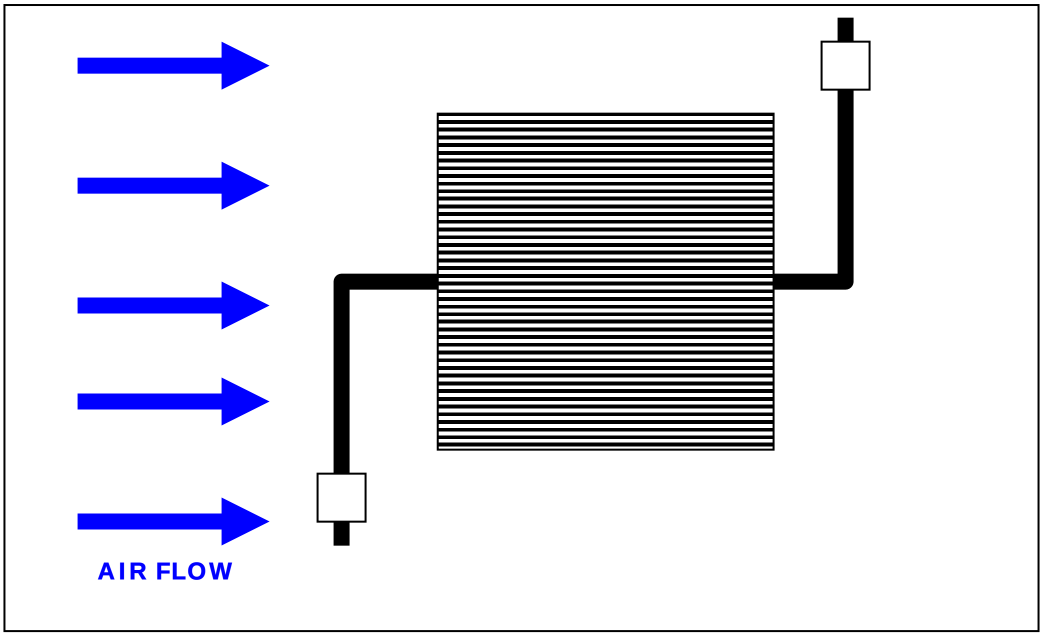
Figure 5. Thermal Performance Requirement



3.4.1 Heatsink Orientation Relative to Airflow

The heatsinks are designed to maximize use of the available space within the volumetric constraint zone. These heatsinks must be oriented correctly relative to the processor volumetric constraint zone and airflow. In order to use this design, the processor must be placed on the PCB in an orientation such that the heatsink fins are parallel to the airflow. Figure 6 illustrates this orientation. A top view of the heatsink assembly is shown.

Figure 6. Air Flow Direction and Heatsink Fin Orientation



3.4.2 Thermal Interface Material (TIM)

The interface between the processor and heatsink base has a significant impact on the overall thermal solution. Specifically, the bond line thickness, interface material area, and interface material thermal conductivity must be selected to optimize the thermal solution.

The thickness of the thermal interface material, commonly referred to as the bond line thickness, should be minimized. A large gap between the heatsink base and processor die yields a greater thermal resistance. The thickness of the gap is determined by the flatness of both the heatsink base and the die, plus the thickness of the thermal interface material, and the clamping force applied by the heatsink attachment method. To ensure proper and consistent thermal performance, the TIM and application process must be properly designed.

Another important aspect of Thermal Interface Materials is the degradation of the thermal impedance over the life of the material. The impedance of the TIM increases over the life of the material; this must be taken into account when designing a thermal solution.

The resistance of the thermal solution increases as the TIM degrades and nears its End of Life. End of Life is defined as a time in the future at which the material is deemed to be at the end of its useful life. The End of Life time varies for TIM material. It is recommended that thermal solution designers work with TIM manufacturers to determine the performance of the thermal interface material and its expected End of Life. System integrators might wish to replace the TIM during scheduled maintenance in order to maintain performance.

Any delay between the TIM material's manufacture and its installation on the heatsink should be minimized. To maximize the thermal solution's End of Life, the TIM material should be applied at End of Line (immediately after it is manufactured).

The heatsink solution was optimized using a high-performance phase-change material (PCM) Thermal Interface Material (TIM) with low thermal impedance, e.g., Honeywell* PCM45 thermal phase-change material. Vendor information for this material is provided in Appendix A. Alternative materials may also be used. The entire heatsink assemblies, including the heatsink attach method, and thermal interface material, must be validated together for specific applications.

3.4.3 Solder-Down Anchors

For platforms that have very limited board space, a clip retention solder-down anchor has been developed to minimize the impact of clip retention on the board. It is based on a standard three-pin jumper and is soldered to the board like any through-hole header. A new anchor design is available with 45° bent leads to increase the anchor attach reliability over time. The part number and vendor information is contained in Appendix A.

4 Reference Thermal Solution

Note: The reference thermal mechanical solution information shown in this document represents the current state of the data and is subject to modification. The information represents design targets, not commitments by Intel.

The reference thermal solution described will be targeted for specific form factors: 1U and PICMG1.3. The keep out zone on the motherboard will remain identical to the Intel® G965 keep out zone for 1U and PICMG1.3.

For ATX and BTX form factor thermal solutions, please refer to *Intel® 3 Series Chipsets — Thermal and Mechanical Design Guide*.

This chapter provides detailed information on operating environment assumptions, heatsink manufacturing, and mechanical reliability requirements for the (G)MCH.

4.1 1U and PICMG1.3 Form Factor Operating Environment

The reference thermal solution compatible with the 1U form factor was designed assuming a maximum local ambient air temperature, T_{LA}, of 40° C with a minimum airflow velocity of 200 lfm [1.02 m/s] present 25 mm [1 in.] directly in front of the heatsink air inlet side. The system integrator should note that board layout may be such that there will not be 25 mm [1 in.] between the processor heatsink and the GMCH. The potential for increased airflow speeds may be realized by ensuring that airflow from the processor thermal solution exhaust is in the direction of the GMCH heatsink. In addition, GMCH board placement should ensure that the GMCH heatsink is within the air exhaust area of the processor heatsink. An example of typical 1U server layout is shown in Figure 7. This layout is based on the *Thin Electronics Bay* specification located at http://www.ssiforum.org. As an added advantage, the GMCH can be located in an area that has a direct fresh air flow. Refer to Figure 7.

Assuming these boundary conditions are met, the reference thermal solutions will meet the thermal specifications for the GMCH. Figure 9 shows the required thermal performance for the Intel GMCH thermal solution. The thermal solution designer must carefully select the location to measure airflow to get a representative sampling. These environmental assumptions are based on a system at sea level.

The 1U reference heatsink solution can also be implemented onto a PICMG1.3 SHB which has an adjacent board or card. See details shown in Figure 8.

Figure 7. 1U System Mechanical Layout

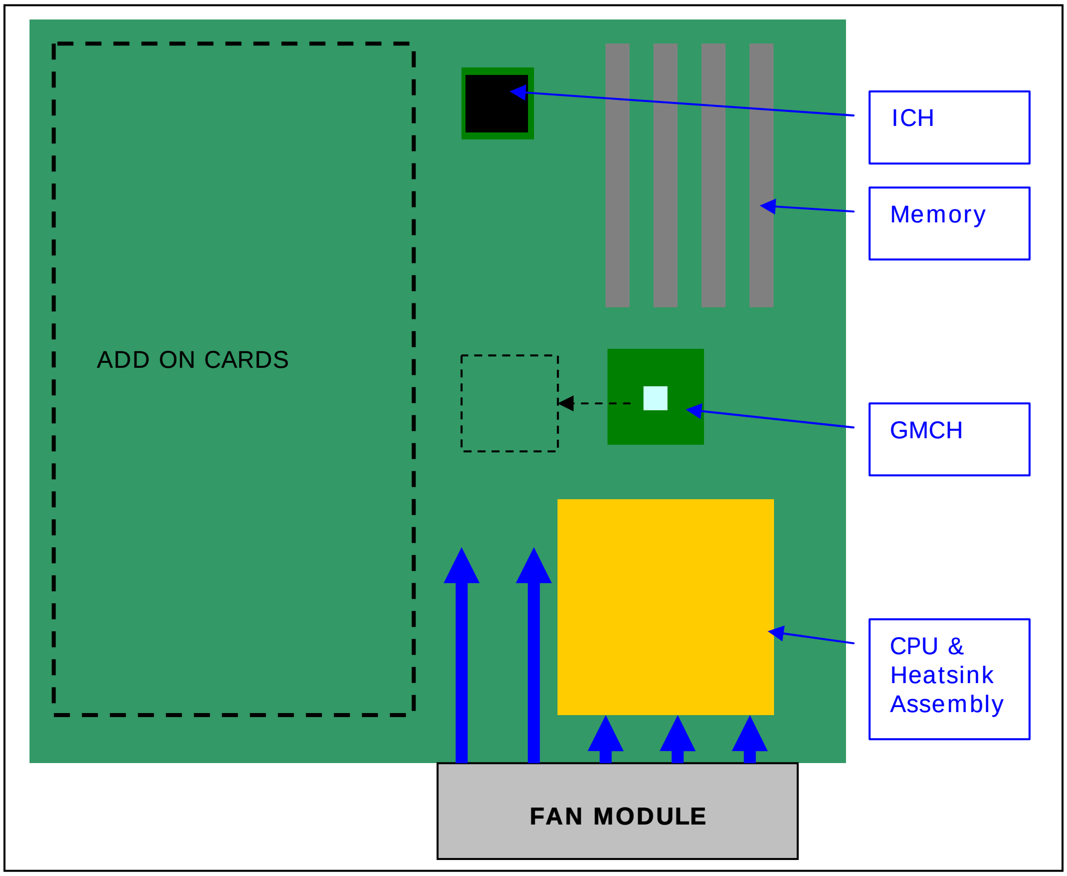
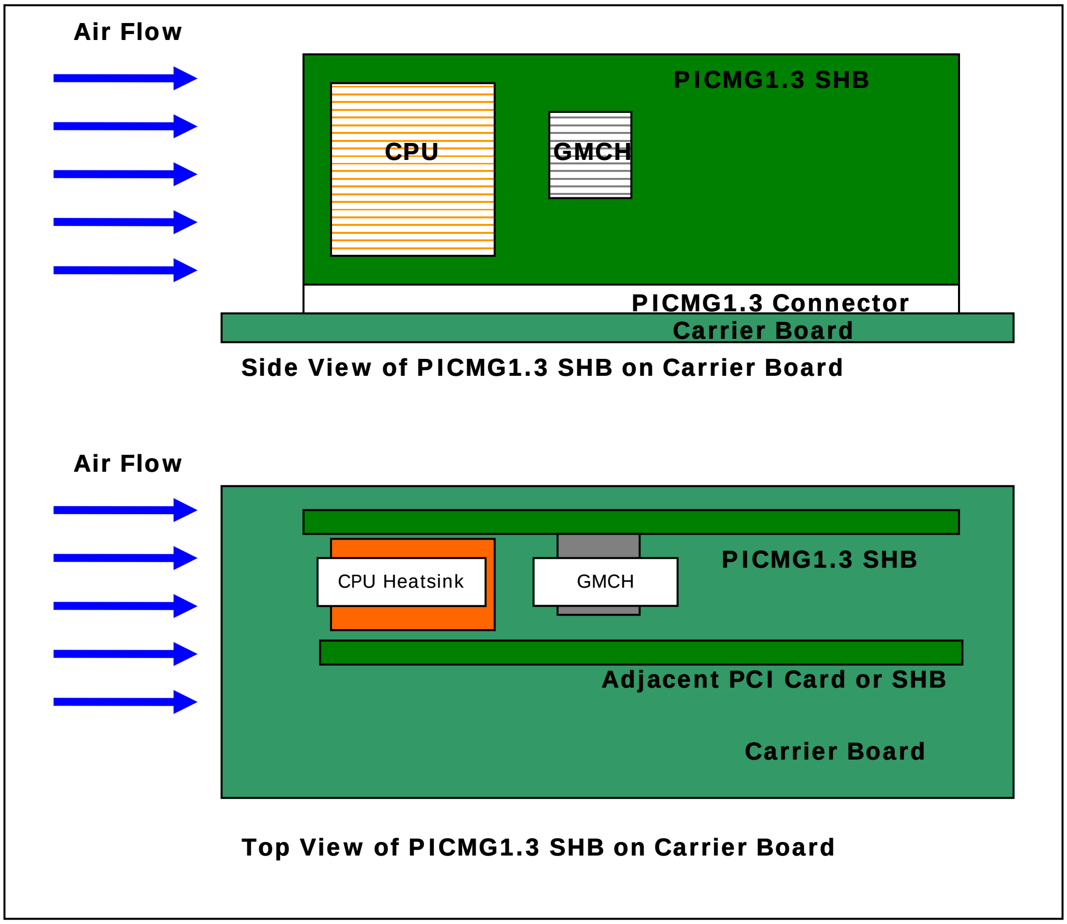


Figure 8. Reference Heatsink for PICMG1.3 Form Factor



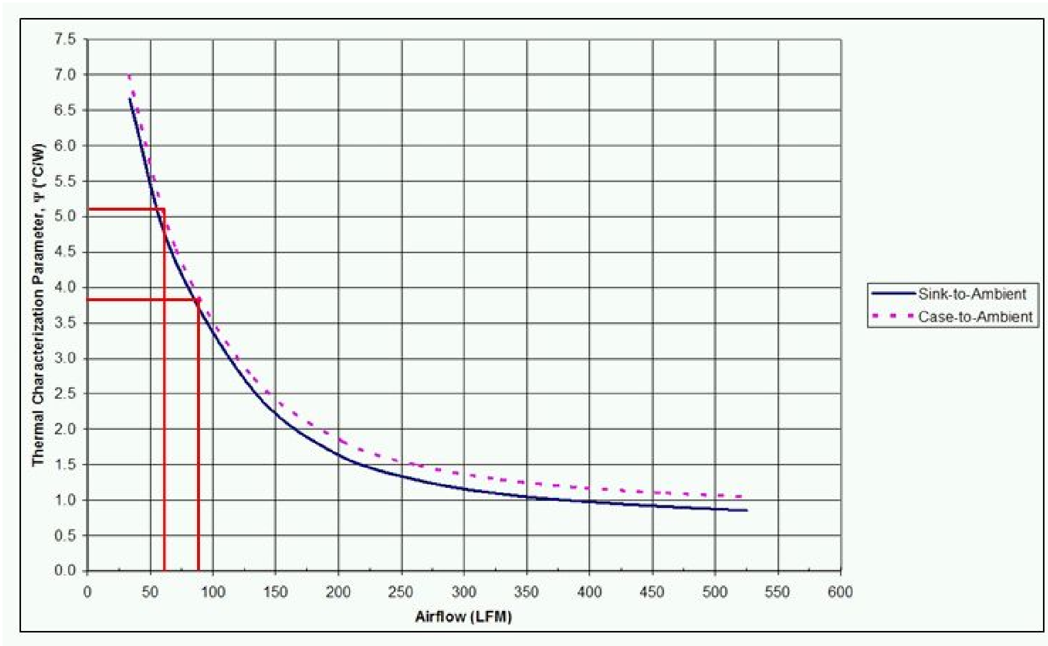
4.2 Thermal Performance of 1U and PICMG1.3 Reference Solution

For environments at T_{LA} of 40° C and 55° C, the required case to ambient thermal resistance will be 5.08 C/W and 3.92 C/W, respectively.

Based on the performance curve shown in Figure 9, at T_{LA} of 40° C and 55° C, it will require 65 LFM and 85 LFM to cool the GMCH within its $T_{c\text{-}max}$ specification.

Because of the high thermal performance required, it is recommended to move the GMCH to the higher air flow location as shown in Figure 7.

Figure 9. 1U and PICMG1.3 Thermal Performance of GMCH Reference Solution



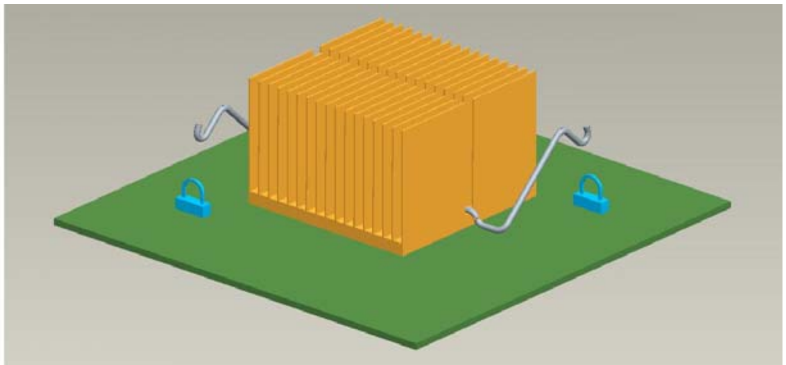
4.3 Reference Design Mechanical Envelope

The motherboard component keep-out restrictions for the GMCH for the 1U and PICMG1.3 form factors are included in Appendix B.

4.4 Thermal Solution Assembly

The reference thermal solutions for the GMCH in 1U and PICMG1.3 form factors are shown in Figure 10. For 1U the heatsink will be mounted horizontally in plane with the chassis, whereas in PICMG1.3 SHB, the heatsink will be mounted vertically with respect to the chassis, where a retention mechanism should be considered to ensure the heatsink stays intact with the SHB.

Figure 10. 1U/PICMG1.3 GMCH Heatsink - Mounted on Board



4.5 Environment Reliability Requirements

The environmental reliability requirements for the reference thermal solution are shown in Table 3. These should be considered as general guidelines. Validation test plans should be defined based on anticipated use conditions and resulting reliability requirements.

Table 3. 1U and PICMG1.3 Reference Thermal Solution Environmental Reliability Requirements

Test[1]	Requirement	Pass/Fail Criteria[2]
Mechanical Shock	• 3 drops for + and - directions in each of 3 perpendicular axes (total 18 drops). • Profile: 50 G trapezoidal waveform, 11 ms duration, 4.3 m/s [170 in/s] minimum velocity change. • Setup: Mount sample board on test fixture. Include 550 g processor heatsink.	Visual\Electrical Check Cross section should have crack length < 50 %
Random Vibration	• Duration: 10 min/axis, 3 axes • Frequency Range: 5 Hz to 500 Hz • Power Spectral Density (PSD) Profile: 3.13 g RMS	Visual/Electrical Check Cross section should have crack length < 50 %

Test[1]	Requirement	Pass/Fail Criteria[2]
Thermal Cycling	• -40° C to +85° C, 900 cycles	Thermal Performance
Unbiased Humidity	• 85 % relative humidity / 55° C, 1000 hours	Visual Check

NOTES:
1. The above tests should be performed on a sample size of at least 12 assemblies from 3 different lots of material.
2. Additional Pass/Fail Criteria may be added at the discretion of the user.

Appendix A: Enabled Suppliers

These vendors and devices are listed as a convenience to the embedded customer base, but Intel does not make any representation or warranty whatsoever regarding quality, reliability, functionality, or compatibility of these devices. The list and/or these devices may be subject to change without notice.

Table 4. 1U / PICMG1.3 Intel Reference Heatsink Enabled Suppliers for GMCH

Component	Supplier	Intel Part Number	Vendor Part Number	Contact Information
1U Copper Heatsink gasket, and pre-applied Honeywell* PCM45F TIM	Cooler Master*	N/A	ECB-00265-01-GP	Wendy Lin (USA) (510)770-8566 ext. 211 wendy@coolermaster.com
Thermal Interface Material	Honeywell*	N/A	PCM45F	Paula Knoll 858-279-2956 Paula_knoll@honeywell.com
Heatsink Attach Clip	CCI/ACK*	A69230-001	N/A	Harry Lin (USA) 714-739-5797 hlinack@aol.com Monica Chih (Taiwan) 866-2-29952666, x131 Monica_chih@ccic.com.tw
	Foxconn*		N/A	Bob Hall (USA) 503-693-3509, x235 bhall@foxconn.com
Solder-down Anchor	Foxconn*	A13494-005	N/A	Julia Jiang (USA) 408-919-6178 juliaj@foxconn.com

Table 6. Supplier Contacts

Supplier	Contacts	Phone	Email
AVC (Asia Vital Components)	David Chao	+886-2-2299-6930 ext.7619	david_chaoi@avc.com.tw
	Raichel Hsu	+886-2-2299-6930 ext.7630	raichel_hsi@avc.com.tw

CCI (Chaun Choung Technology)	Monica Chih	+886-2-2995-2666	monica_chih@ccic.com.tw
	Harry Lin	+1(408) 919-6121	hlinack@aol.com
Foxconn	Jack Chen	+1(408) 919-6135	jack.chen@foxconn.com
	Wanchi Chen	+1(714) 626-1376	wanchi.chen@foxconn.com
Wieson Technologies	Beatrice Chang	+886-2-2647-1896 ext.6395	beatrice@wieson.com
	Edwina Chu	+886-2-2647-1896 ext.6390	edwina@wieson.com

Appendix B: Mechanical Drawings

The following table lists the mechanical drawings available in this document.

Figure 11. GMCH Package Drawing

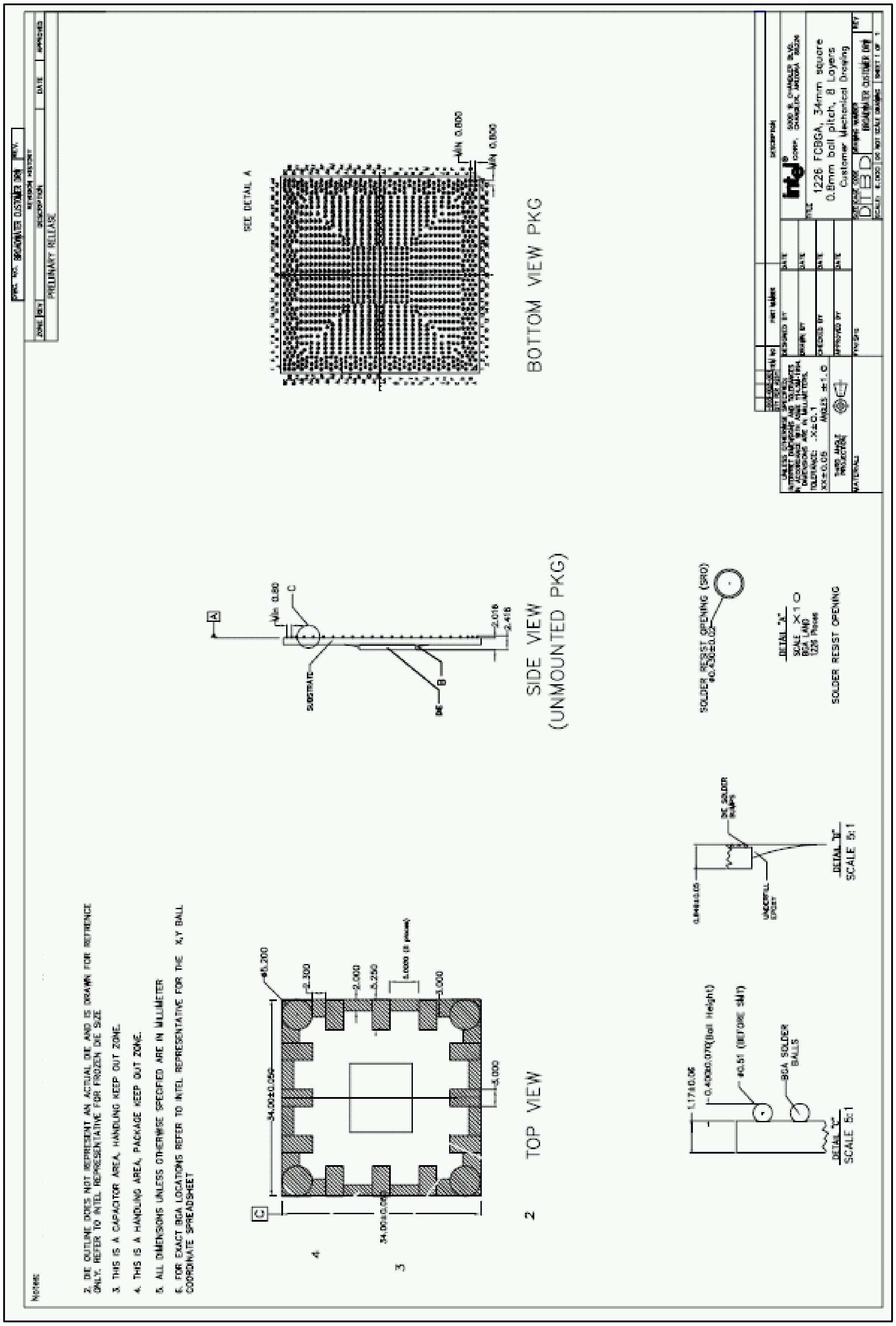


Figure 12. GMCH Component Keep-Out Restriction for 1U/PICMG1.3 Platforms

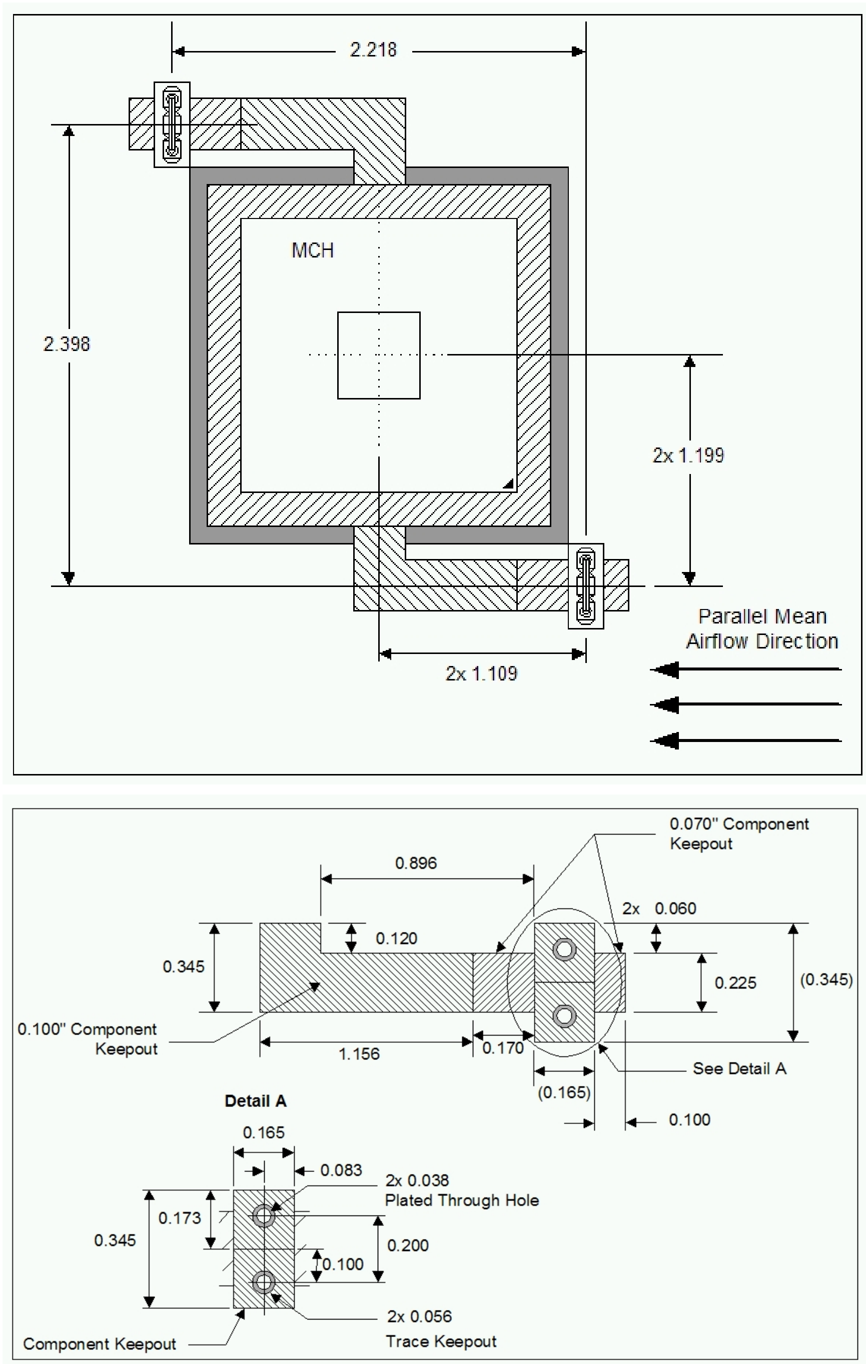
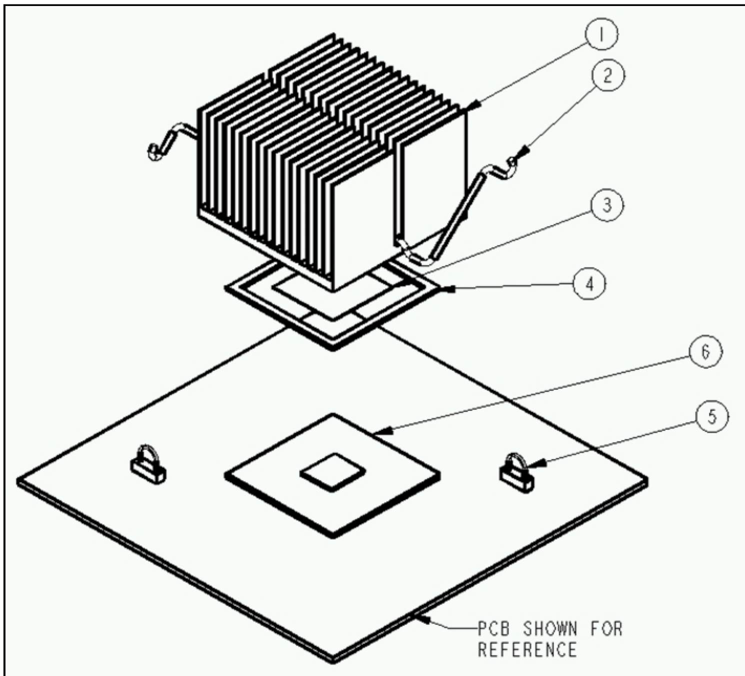


Figure 13. GMCH Reference Heatsink Assembly for 1U/PICMG1.3 Platforms



1. Copper Heatsink
2. Heatsink clip
3. TIM
4. Gasket
5. Anchor
6. GMCH package

Figure 14. GMCH Reference Heatsink for 1U/PICMG1.3 Platforms

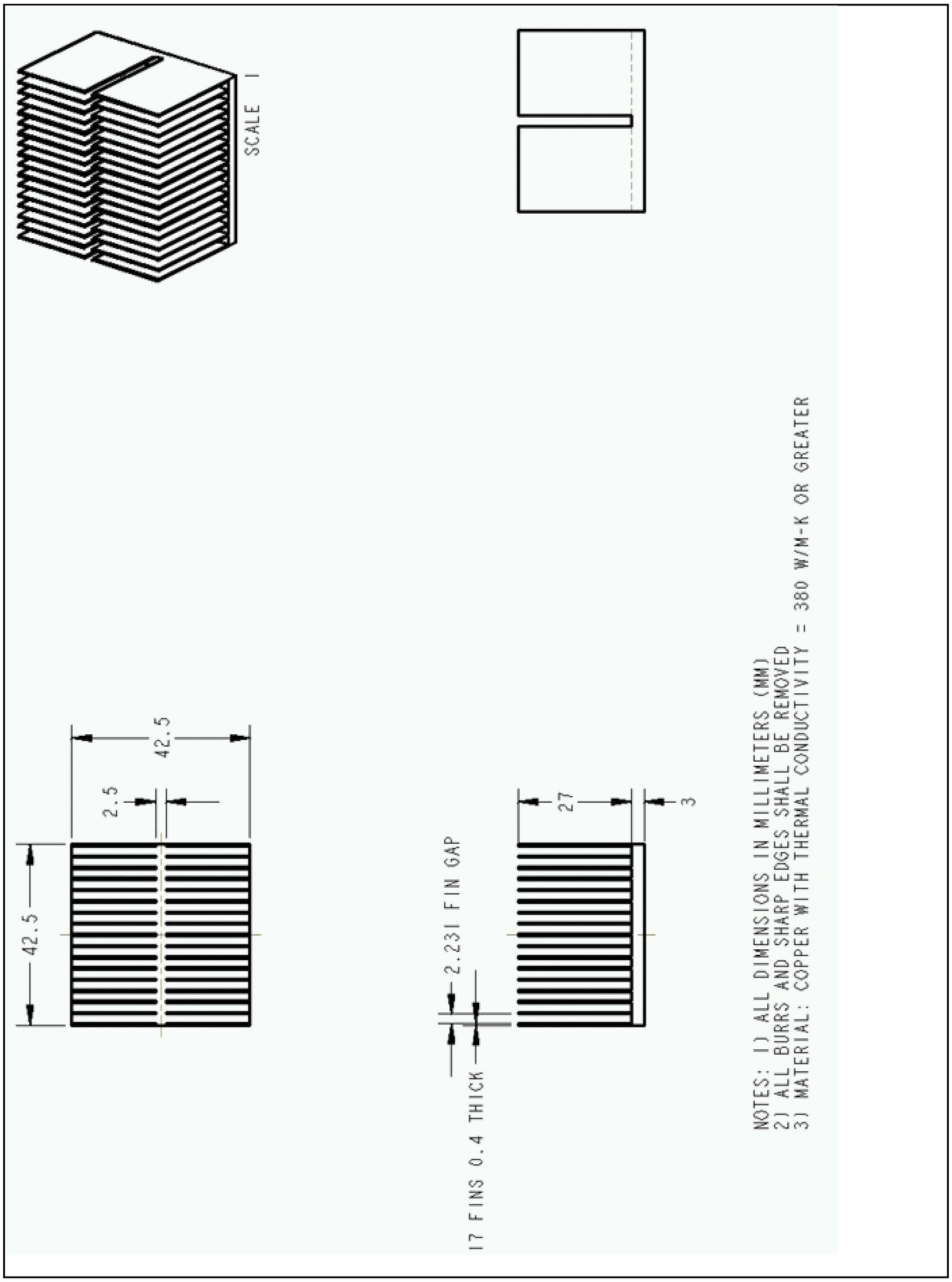


Figure 15. GMCH Reference Heatsink Gasket for 1U/PICMG1.3 Platforms

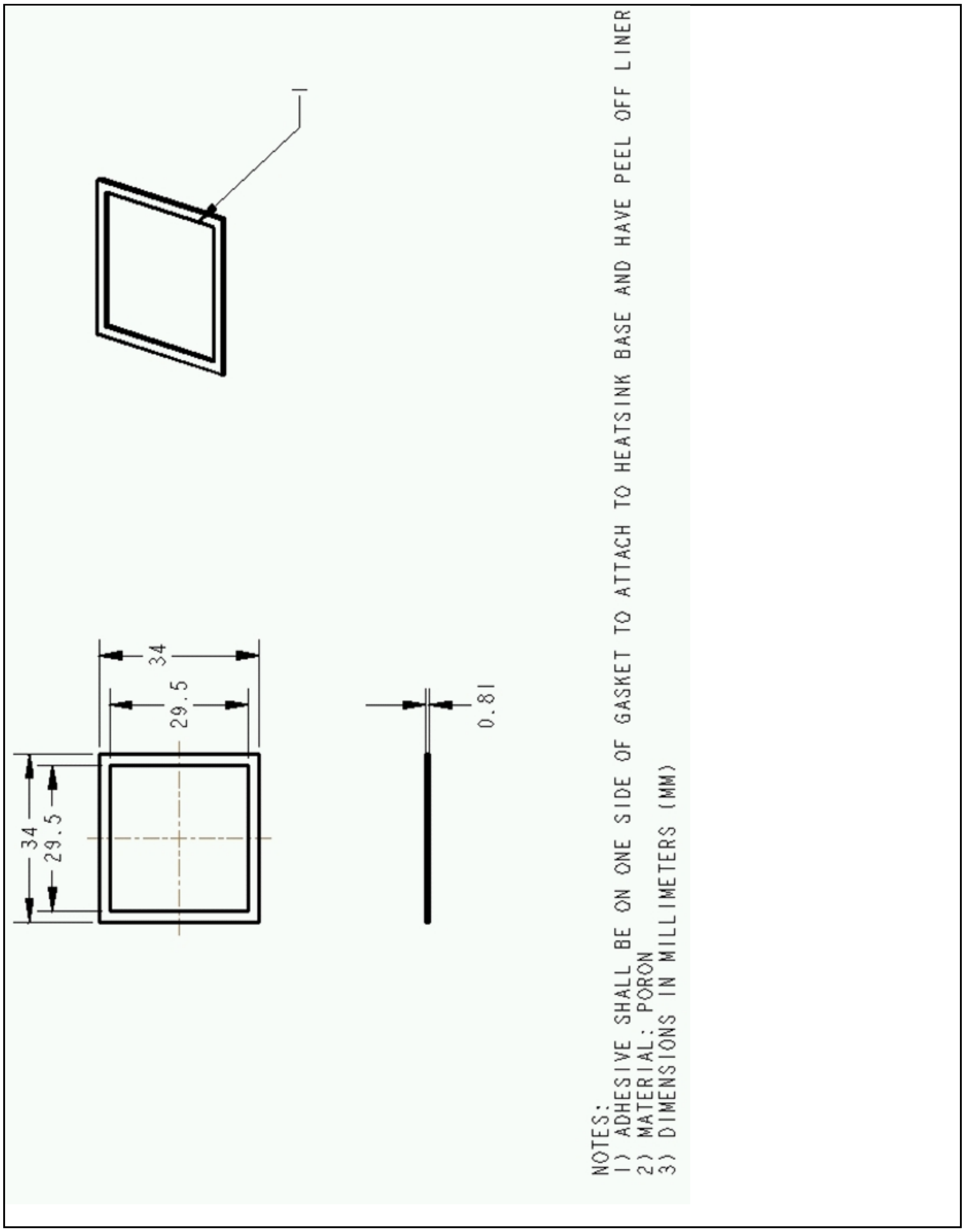


Figure 16. GMCH Reference Heatsink Clip for 1U/PICMG1.3 Platforms